Combing Visible and Infrared Spectral Tests for Dust Identification

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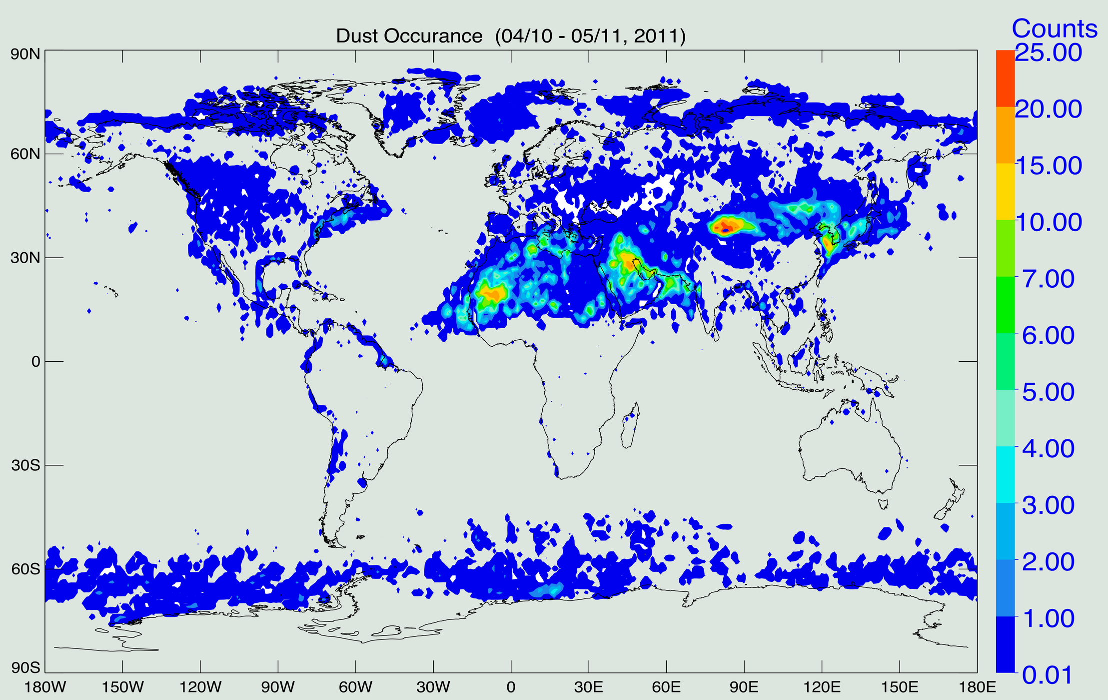
Objective

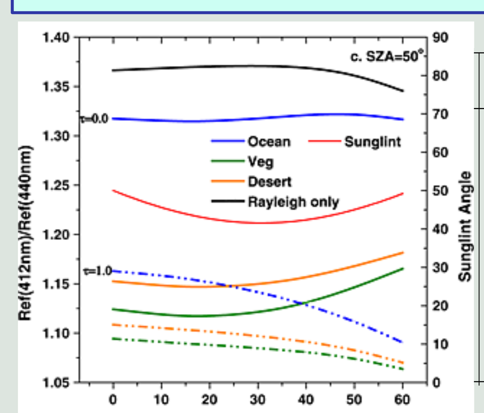
- The MODIS Dark Target aerosol algorithm over Ocean (DT-O) uses spectral reflectance in the visible, near-IR and SWIR wavelengths to determine aerosol optical depth (AOD) and Angstrom Exponent (AE). Even though DT-O does have "dust-like" models to choose from, dust is not identified a priori before inversion. The "dust-like" models are not true "dust models" as they are spherical and do not have enough absorption at short wavelengths, so retrieved AOD and AE for dusty regions tends to be biased. The inference of "dust" is based on post-processing criteria for AOD and AE by users.
- Dust aerosol has known spectral signatures in the near-UV (Deep blue), visible, and thermal infrared (TIR) wavelength regions. Multiple dust detection algorithms have been developed over the years with varying detection capabilities. Here, we test a few of these dust detection algorithms, to determine whether they can be useful to help inform the choices made by the DT-O algorithm.
- We evaluate the following methods:
  - The multichannel imager (MCI) algorithm uses spectral threshold tests in (0.47, 0.64, 0.86, 1.38, 2.26, 3.9, 11.0, 12.0 μm) channels and spatial uniformity test [*Zhao et al*., 2010].
  - The NOAA dust aerosol index (DAI) uses spectral contrast in the blue channels (412nm and 440nm) [Ciren and Kundragunta, 2014] .
- The MCI is already included as tests within the "Wisconsin" (MOD35) Cloud mask algorithm.

Where is dust detected? Apr-May 2011



The MOD35 dust flag (MCI algorithm) detects dust where dust is expected, including West Africa, Mediterranean and East Asia. It also finds dust in high latitudes and along some coastlines where it is not expected. It fails to detect dust crossing the oceans. Adjusting thresholds may resolve some of the problems.

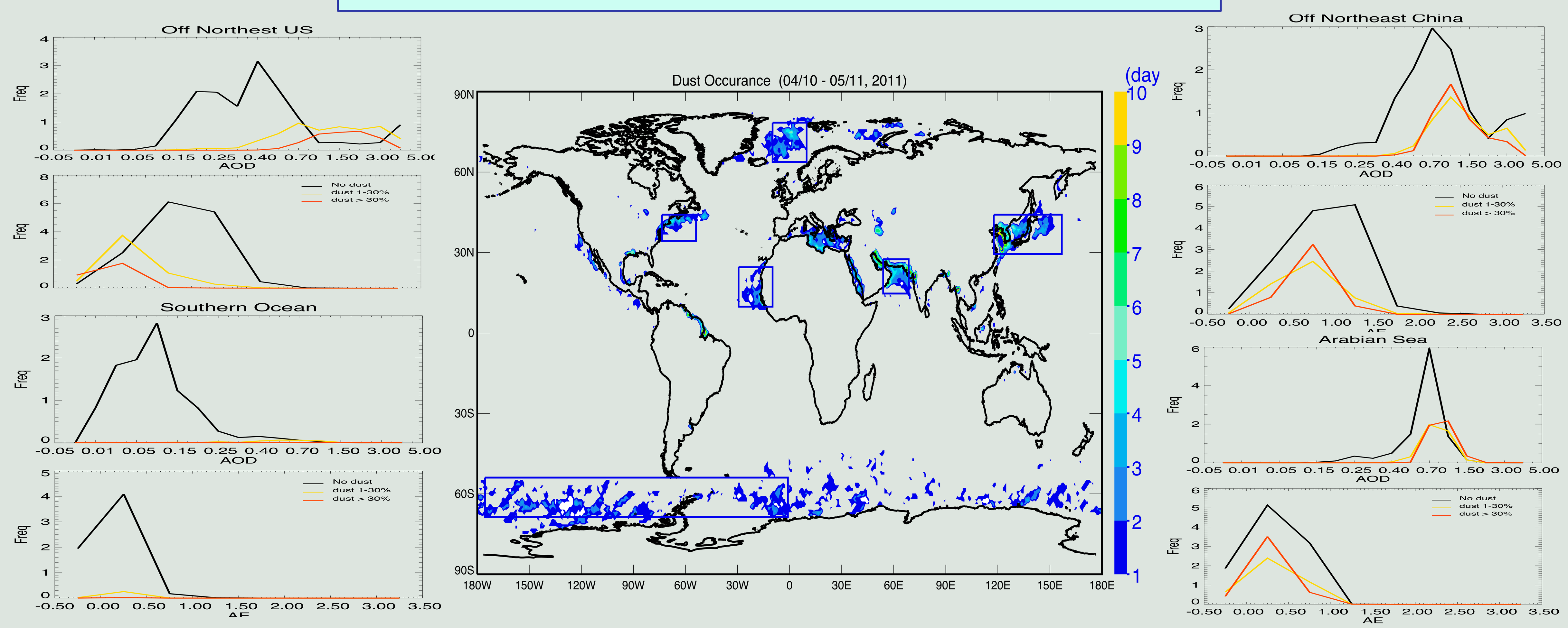
NOAA Dust Aerosol Index for MODIS



Method	Notes	Authors
Uses MODIS 412,440 and 2130 $DAI = -100[\log_{10}(R_{412nm}/R_{440nm}) - \log_{10}(R'_{412nm}/R'_{440nm})]$ (R' is Rayleigh scattering as computed by 6s) $NDAI = -10(\log_{10}(R_{412nm}/R_{2130nm}))$	DAI may only detect absorbing versus non absorbing aerosol. NDAI is needed to separate dust and smoke. 4 is DAI threshold -10 is the NDAI threshold	Ciren & Kondragunta 2014, JGR

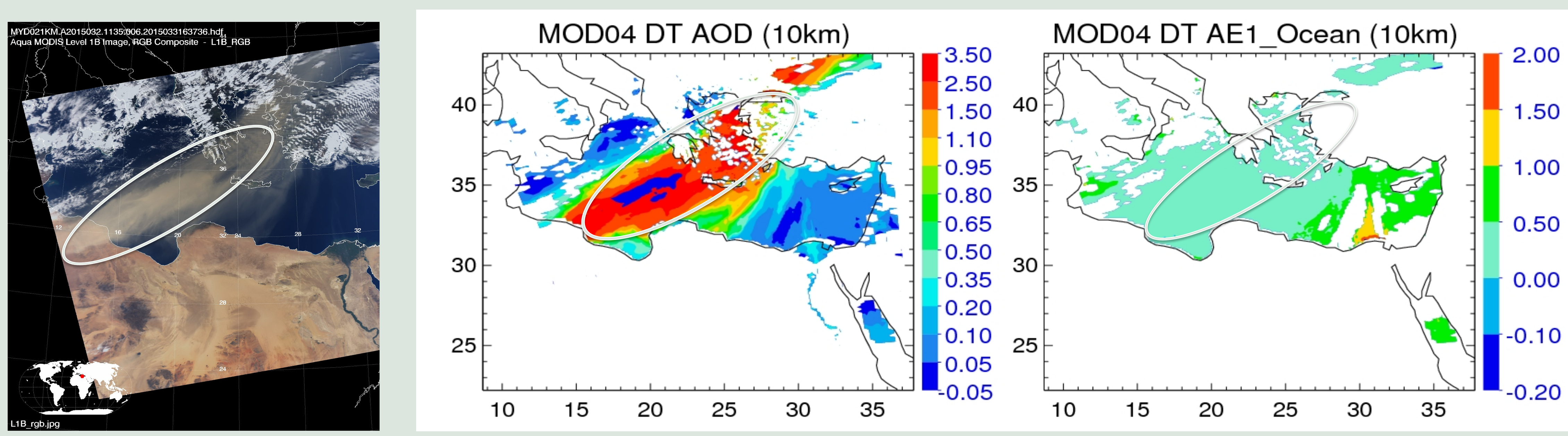
The NOAA DAI algorithm takes advantage of the different spectral dependence of Rayleigh scattering, surface reflectance, and dust absorption to detect absorbing aerosols. Rayleigh scattering increases with decreasing wavelength (high R412/R440) while dust absorption reduces the spectral contrast in (R412/R440). The difference in observed reflectance ratio versus reflectance ratio from pure Rayleigh scattering forms the basis of the algorithm. A non-dust index NDAI is used on the DAI positive detections to separate dust from absorbing smoke based on the higher reflectance of dust at 2130nm due to its larger particle size.

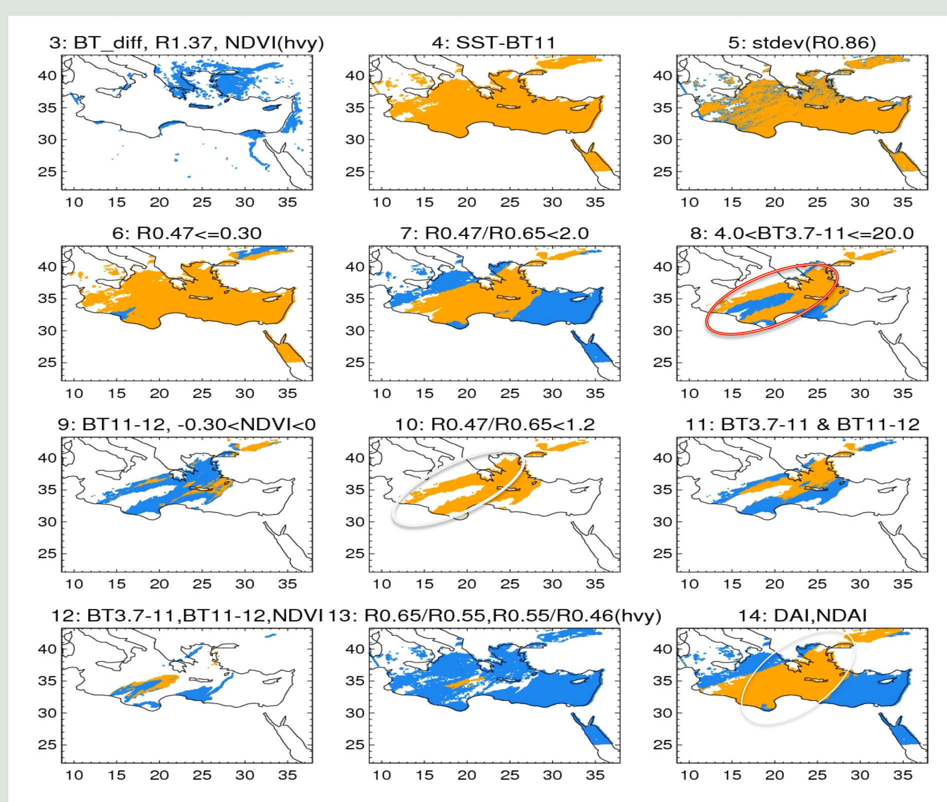
Where is dust detected and what is its AOD?

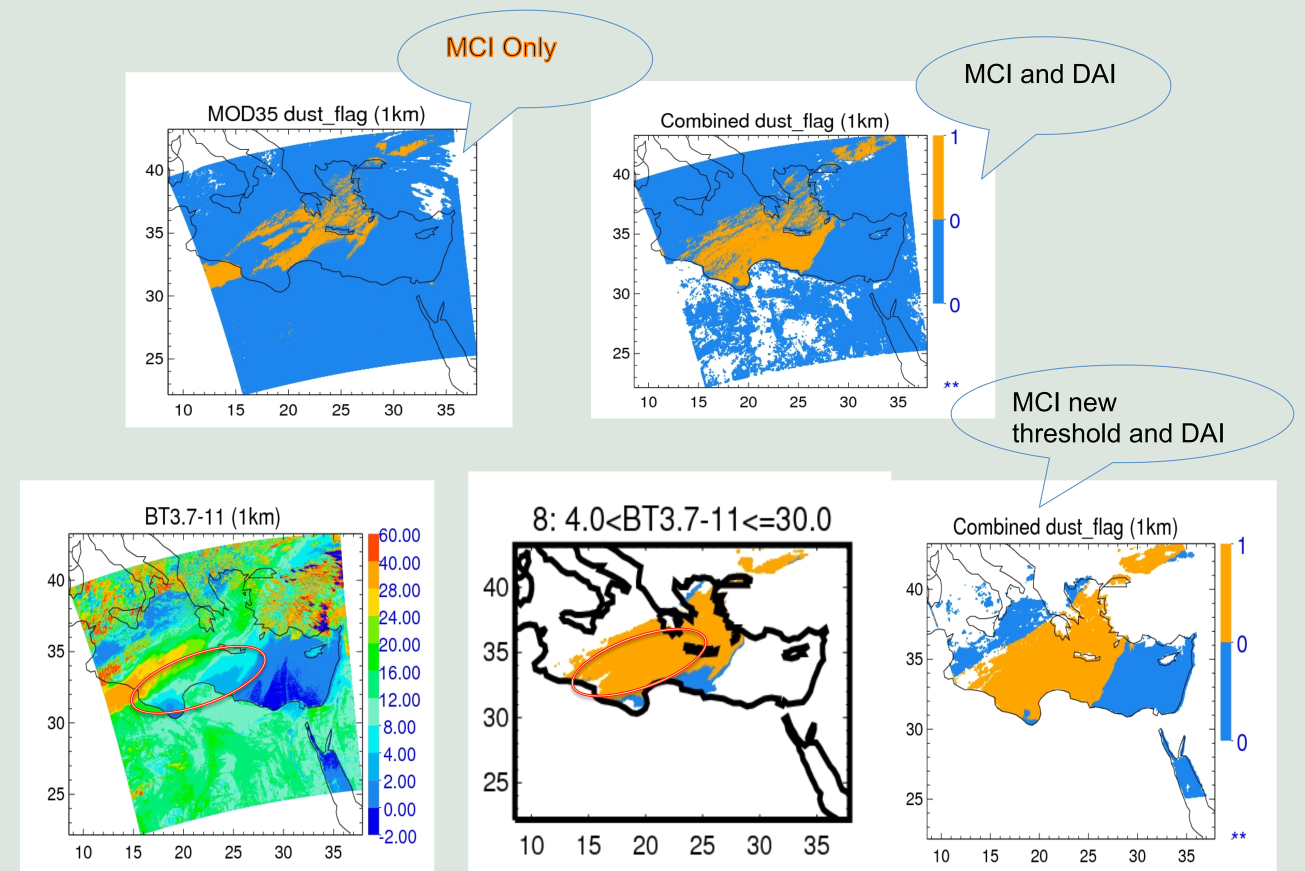


Histograms of MOD04 DT aerosol optical depth (AOD) and angstrom exponent (AE) stratified with the percentage of MOD35 dust flag indicates dusty pixels have higher AOD and lower AE near coastal northern China, the northwest US, and the Arabian Sea. Dust in the southern oceans is likely wrongly identified.

Evaluation, Fine-Tuning and Consolidation of the MCI and DAI Algorithms







By following the sequence of individual spectral tests in the MCI algorithm, it is possible to identify which tests failed to detect the dusty pixels and the thresholds need to be adjusted. In the example above, test 8 in MCI (the brightness temperature difference between 3.7 μm and 11 μm fails in the center of a heavy dust plume. Relaxing the upper threshold from 20K to 30K allows test 8 to pass and the final identification of the heavy dust pixels in the center of the plume. Adding the NOAA DAI test also generally increases the area of dust detection.

Dust Spectral Tests

Spectral tests in MCI and DAI algorithms are numbered in order to trace the failed tests and identify potential tunable thresholds. In the following, tests 0 and 4-8 are required to pass in sequential order for all dust pixels over land and water, respectively. Each test in orange leads to dust detection independently.

MCI tests (Zhao et al. 2010):

First screen out potential clouds (6.7μm for high clouds and 11-12 μm BTD for thin cirrus clouds)

Tests for Daytime Land Surfaces

0: BT11-BT12 ≤ -0.5, BT3.7-BT11 ≥ 20.0, and R1.38 < 0.035
1: {(R0.65-R0.47)/(R0.65+R0.47)}²/R0.65² > 0.005
and (NDVI/ R0.65)² < 0.08
2: BT3.7-BT11 ≥ 25.0
3: BT11-BT12 < -0.5, BT3.7-BT11 ≥ 25.0 & R1.37 < 0.055, (NDVI/R0.65)²<0.2 (heavy dust)

Tests for Daytime Water Surfaces

4: SST-BT11 test. The thresholds depends on value of BT11-BT12.
5: stdev(R0.86) < 0.005.
6: R0.47 ≤ 0.30,
7: R0.47 / R0.65 < 2.0,
8: BT3.7-BT11 > 4.0, and BT3.7-BT11 ≤ 20.0
9: BT11-BT12 < 0.10, NDVI ≤ 0.0, and NDVI ≥ -0.3
10: R0.47/R0.65 < 1.2
11: BT3.7-BT11 > 10.0 and BT11-BT12 < -0.1
12: T3.7-BT11 > 20.0, BT11-BT12 < 0.0, -0.3 ≤ NDVI ≤ 0.05
13. R0.65/R0.55 ≥ 1.15 and R0.55/R0.47 ≥ 1.15

NOAA DAI and NDAI tests:

14: DAI (R0.412,0.440)>4 and NDAI (R0.410, R2.110)>-10 for ocean.

Table 1. Ratio of the number of dusty pixels detected by MCI and DAI versus the combined algorithm.

Granule	MOD35/ Combined	DAI/Combined	Scene description
2009.196.1015	0.66	1.0	Dust Plume, Persian Gulf
2014.113.1110	0.76	0.66	Dust Plume, Mediterranean
2014.162.1505	0.87	0.74	Dust Plume, off west Africa
2010.048.1150	0.60	1.0	Dust Plume, Mediterranean Sea
2013.053.1115	0.92	1.0	Dust Plume, Mediterranean Sea
2015.032.1135	0.72	1.0	Dust Plume, Mediterranean Sea
2013.018.0550	0.008	1.0	Dust storm over Northeast China
2007.296.2140	0.0004	1.0	Smoke off California

Summary and Future Work

- MOD35 dust flag identifies dusty pixels in heavy dust areas over land and near the coast of East Asia, the Mediterranean Sea, off west Africa and north America. It fails to detect thin dust in mid-ocean. False detection is found over high latitude oceans.
- The NOAA DAI and NDAI tests generally detect more dusty pixels.
- Combined MCI and DAI tests tend to produce better results.
- Following individual spectral tests in MCI allows targeted adjustment of certain thresholds to produce better results.
- Independent validation using active remote sensing data is needed.
- A dust model will be applied following identification of dusty pixels in the DT algorithm.

References:
1. Zhao, T. X.-P., S. Ackerman, and W. Guo (2010), Dust and smoke detection for multi-channel imagers, *Remote Sens.*, **2**, 2347–2368, doi:10.3390/rs2102347.
2. Cho, H.-M., S. L. Nasiri, P. Yang, I. Laszlo, and X. Zhao (2013), Detection of optically thin mineral dust aerosol layers over the ocean using MODIS, *J. Atmos. Oceanic Technol.*, **30**, 896–916.
3. Ciren, P., and S. Kondragunta (2014), Dust aerosol index (DAI) algorithm for MODIS, J. Geophys. Res. Atmos., 119, 4770–4792, doi:10.1002/2013JD020855.